# Metamaterial in Finline Configuration

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*Abstract* – **This paper presents the results of experimental study of finlines, periodically loaded by split-ring resonators (SRR) and wires. These are the common elements used to construct metamaterials – artificial materials having simultaneously negative effective magnetic permeability and dielectric permittivity. The transmission measurements of SRR-and-wire-loaded finline, carried out around 3 GHz, show clearly a pass-band emergence in the region of non-transmission of the SRR-loaded and wires-loaded finlines. This behaviour, predicted by theory, is considered an indirect evidence of simultaneously negative effective permittivity and permeability of the structure.**

*Keywords* – **metamaterial, split-ring resonator, finline**

## I. Introduction

Metamaterials are a novel kind of artificial materials that exhibit negative effective magnetic permeability and dielectric permittivity. The idea that a negative macroscopic parameters media would support wave propagation belongs to V.Veselago, who studied it theoretically in 1968 [1]. As such media are not readily found in nature, the subject was not further developed until recently, when Pendry [2] suggested that negative effective permeability in a narrow frequency band could be achieved through artificial magnetism of resonant diamagnetic particles known as split-ring resonators (SRR). Subsequently, Shelby [3] used a combination of SRR array and straight thin wires array, the latter claimed to have negative effective permittivity up to some frequency, to demonstrate for the first time a passband in the frequency region where $\varepsilon_{r,\ eff}$ and $\mu_{r,\ eff}$ are simultaneously negative. Other experimental studies followed employing mainly free-space or parallel-plate waveguide metamaterial configuretions. Although these experiments are highly valuable for understanding the electromagnetic phenomena in metamaterials, the structures used are three-dimensional and of considerable size, and are not feasible for practical microwave implementations. Therefore, a number of subsequent studies focus on microstrip and waveguide metamaterial implementations of filters and other devices.

In this paper, we employ the main principles of metamaterial construction to study a transmission line, loaded with SRR and wires, that exhibits a transmission passband due to negative effective permittivity and permeability. The transmission line itself is an unilateral finline – a slotline inside a rectangular waveguide. The main advantages of this configuration are:

- The field is concentrated inside the slot providing strong excitation of the SRRs;
- The line is shielded by the waveguide so there are no radiation losses;
- The structure is inherently two-dimensional and therefore can include SMD elements such as capacitors, inductors, diodes, etc.;
- Small size and easy fabrication.

## II. Metamaterial-Loaded Finline

The finline is actually a slotline placed in the E-plane in the middle of a standard rectangular waveguide with dimensions of 34x72 mm. The frequency range of waveguide operation is 2.60 ÷ 4.16 GHz. The finline is etched on a standard PCB substrate (FR4) with thickness of 1.5 mm and relative permittivity $\varepsilon_r = 4.4$. This kind of substrate is chosen for its low price and availability considerations, but, as this material is not intended for microwave applications because of its high loss tangent, it degrades to some extent the finline performance. In principle, high quality microwave materials (for example, Rogers Duroid 5880™) should be used.

The finline dimensions are:

- Gap between the strips: 3 mm;
- Full length (with taper sections): 16 cm;
- Slotline length (without taper sections): 8 cm.

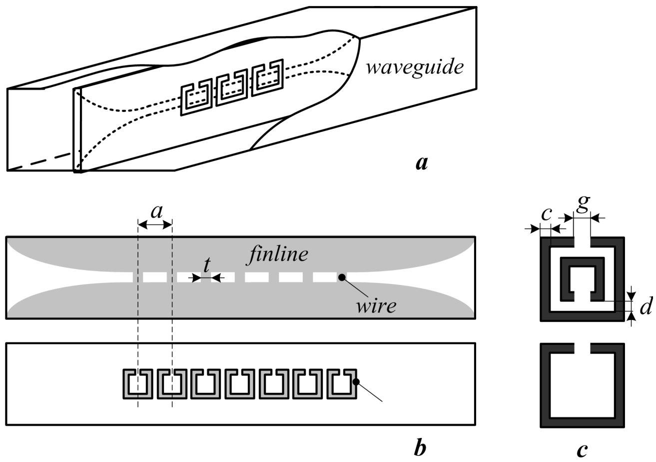


Fig. 1. Full waveguide structure (a), loaded finline – front- and backside view (b) and the two types of SRR used.

To ensure good electrical contact between the finline strips and the waveguide, springing elements (bendable wires) have been soldered in longitudal direction at the finline edges. The full waveguide structure is presented in Fig.1(a).

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The finline is loaded periodically by wires, as shown in Fig.1(b). The SRR are etched on the back side of the substrate (opposite to the strips) to ensure that they are excited by the transversal magnetic field component. The operation of the SRR is based on the Lenz law – the external field, coaxial with the split-ring resonator, excites currents along the SRR strips. The magnetic field of the excited current is opposite to the external field so the particle is diamagnetic in nature. At the resonance frequency of the particle the excited magnetic field is greatly enhanced and, as it opposes the incident field, the macroscopic effect is negative permeability.

Two types of structures have been constructed and studied. Type 1 consists of double SRR (Fig.1c) with dimensions l=7.5mm, d=0.2 mm, c = 0.9 mm, g = 0.9 mm, which are resonant around 3 GHz. The wires are 2 mm wide. The period is a=9mm and the finline is loaded by 9 SRR/wires. Type 2 employs single SRR (Fig.1c) with dimensions l = 7mm, c = 0.7 mm, g=1 mm and resonance frequency of 3.66 GHz. The period is a=8 mm and the number of SRR/wires is 5.

The finline characteristic impedance, effective dielectric permittivity and propagation constant as a function of frequency have been assessed using the formulas in [4]. The characteristic impedance varies from 140.8 to 143.2 Ω in the frequency range 2.7 ÷ 3.9 GHz. The calculated finline wave-length for the highest frequency of interest (3.9 GHz) is 5.9 cm, so the SRR and wires sizes and period are much smaller than the finline wavelength.

## III. Measurement Setup

The purpose of the experiment was to measure the level of the signal transmitted through different structures – SRR-only loaded finline, wires-only loaded finline, and the combination of SRR-and-wire loaded finline. As each media separately exhibits negative effective permittivity/permeability in certain frequency range, which corresponds to non-transmission, a transmission band should occur, according to theory, in the range where $\varepsilon_{r,\,eff}$ and $\mu_{r,\,eff}$ are simultaneously negative.

The measurement setup consists of: a signal generator Rohde-Shwartz in the frequency range of 2.5 ÷ 4 GHz, which excites a $TE_{10}$ mode in the waveguide; a spectral analyzer to measure the transmission level.

## IV. Results

Fig. 2 and 3 present the measured level of the transmitted signal in function of frequency. Fig. 2 corresponds to type 1 structure with double SRR and Fig.3 – to single SRR structure type 2. In each figure four graphs are plotted – transmission through the finline (for reference), SRR-loaded finline, wires-loaded finline and SRR-and-wire-loaded finline. The SRR resonance causes transmission level degradation between 2.81-3.12 GHz for double SRRs (Fig. 2) and between 3.55-3.78 GHz for the single SRR structure (Fig. 3). Wires-loaded finline in both cases exhibits poor transmission (minimum 25dB below the finline transmission level). When combining SRRs and wires, an enhanced transmission band (designated with arrows) occurs near the band of non-transmission of the SRR-loaded finline.

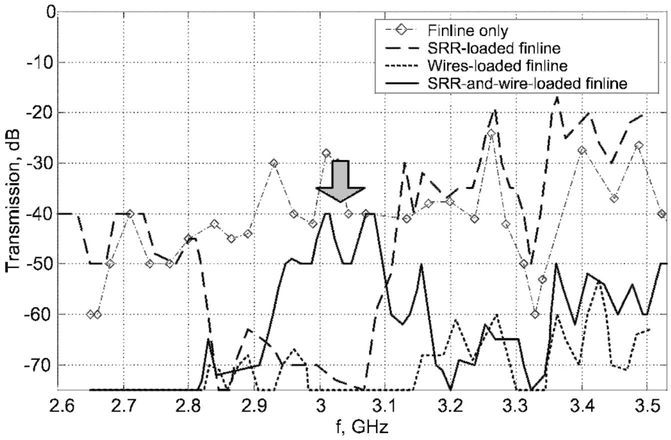


Fig. 2. Measured transmission through structure type 1

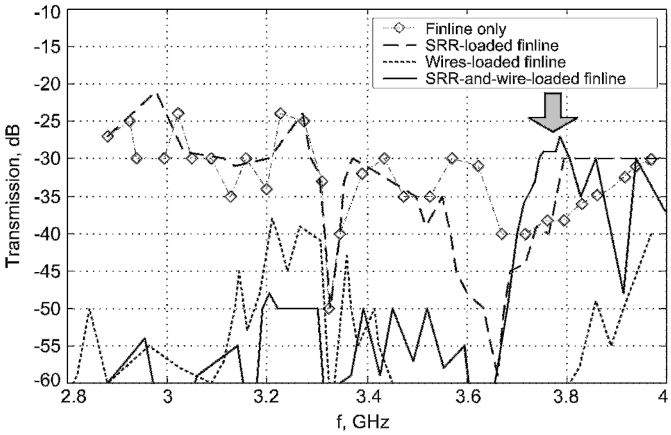


Fig. 3. Measured transmission through structure type 2

## V. Conclusion

The paper presented experimental results of transmission measurement of metamaterial-loaded finline. An enhanced transmission band is observed near the frequency of SRR resonance. This behaviour is in agreement with theory [1] and other experimental studies [3]. The conducted experiments, however, do not explicitly prove the existence of negative effective parameters. More detailed analysis should include phase measurement of the transmitted signal through finlines of various length.

## References

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